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The historical facts that brought today's scientists to use optical communication systems, and the possible advantages or disadvantages of using fiber optic transmission medium were investigated. The requirements and characteristics of the optical links and the problems related to their implemantation were studied. Today's applications as well as the future ones are discussed. An economic analysis and an effectiveness analysis was carried out to stablish future trends.

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SURVEY OF CURRENT TECHNOLOGY RELATED TO FIBER OPTICS

by

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Lieutenant-commander
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT AND MASTER OF SCIENCE IN
COMPUTER SYSTEMS MANAGEMENT

from the

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ABSTRACT

The historical facts that brought today's scientists to use optical communication systems, and the possible advantages or disadvanteges of using fiber optic transmission medium were investigated. The requeriments and characteristics of the optical links and the problems related to their implementation were studied. Today's applications as well as the future ones are discussed. An economic analysis and an effectiveness analysis was carried out to stablish future trends.

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I. INTRODUCTION

A. GENERAL

Light has been used in communications since the discovery of fire. The burning or not burning of a fire indicated that the enemy was or was not present at some location. Fire's use was limited to short distances in direct line of sight and to very short messages due to both environmental conditions and the low speed of signalling.

The discovery of the laser allowed the attainment of directed light beams. This discovery renewed the old dream of using light to send information.

The extreme sensitivity of lightwaves to atmospheric conditions and the enormous attenuation of such waves in the air forced the researchers to give up on the concept of an 'optical hertzian wire', but had strongly driven the reseach into the field of the optical waveguides, capable of carrying light signals with acceptable attenuation.

B. HISTORICAL BACKGROUND

The origin of the search for optical transmission of information began with the creation of man. Every time, man's curiosity drove him to look through a hole to see what was happening on the other side. It is believed that the

ancient Egyptians, in the first century B.C., made glass portraits by drawing together various colored glasses, arranging them to form a picture, and then cutting this assembly into cross sections, much as fused fiber bundles are made today.

Venetians and Baleareans in the fifteenth and sixteenth centuries tried to illuminate rooms in the interior of their houses using rods of blown white glass.

John Tyldall (Ref. 1), an Irish physicist, gave the first known demonstration of internal reflection of light in a fiber-like geometry in May of 1857 before the Royal Institution of London. In this demonstration, 'the lecturer...... permitted water to spout from a tube, the light on reaching the limiting surface of air and water was totally reflected and seemed to be washed downward by the descending liquid'.

Approximately ten years later, Alexander Graham Bell (Ref. 2) studied the possibility of transmitting speech on a beam of light. In this century, Hondros and Debye (Ref. 2) made a theoretical study of dielectric waveguides and Schriever got some experimental results.

The modern era in optical communications began in 1954 when Van Hell and Hopkings, independently, discovered the cladded dielectric waveguide.

K. Charles Kao (Ref.3) at Standard Laboratories Limited in Harlow, England, in 1964, recognized the possibility of using modulated light, guided in a glass fiber, as a wide band transmission medium.

After this discovery a continuous sequence of milestones brought fiber optics to a point where the number of its

applications began to soar.

C. ADVANTAGES AND DISADVANTAGES

Fiber optics technology has a certain number of advantages and disadvantages when compared with electronic technology.

1. High Capacity

The amount of information that can be sent over a channel depends on the frequency of the carrier. Hartley (Ref.4), proved in 1928 that a given bandwidth and a certain period of time are required to transmit a certain amount of information. Shannon proved later that the sending of signals through a channel is limited by the bandwidth of the channel. Bandwidth can be considered as the difference between the higher and the lower frequencies that can be sent through the channel.

The frequency of light is much higher than the frequencies of currents used in conventional communications, allowing higher speed of transmission. The characteristics that limit that speed in fiber optics are discussed later.

2. Communications Security

With the capability of industry today, one can say that communications using fiberglass are very secure. Electromagnetic fields do not affect the fiberglass which is non conductive, and cannot be affected by jamming techniques, tapping or nuclear radiation.

3. <u>Radiation and Conductivity</u>

Fiber glass does not irradiate. There is no cross talk among optical fibers, or between optical fibers, and no electrical conduction occur. Because glass is a very good insulator there is no concern about grounding, shorting, or impedance matching.

4. <u>Cost</u>

At the end of this thesis a cost effectiveness analysis is made. As a first approximation it can be said that the development of this new material will help solve the problem of vanishing of metals. Strands of fiber optic cable are made of sand which is nearly costless.

5. <u>Disadvantages</u>

Fiber optic cable can not be used as a medium to transfer energy. As a result in long distance applications, repeaters have to be used and light has to be converted into electric signals in order to be amplified. The need for conventional wires are still evident.

Fiber optic connectors are fragile and can be easily damaged. If a fiber is broken it will be very difficult to weld and an increase in losses will appear.

II. SYSTEM REQUIREMENTS

A. LINK CHARACTERISTICS

To have a successful communications system, it is necessary to have a transmission medium, a source of light and three fundamental requirements:

1) A transducer, to convert an electrical input signal into light to be transmitted through the fiber cable. The source of light must be capable of being modulated.

2) The fiber cable itself must be capable of being used as a medium through which light can propagate.

3) A detector which converts received light signals back into an electrical signal.

To communicate over long distances requires additional devices: (1) light amplifiers, used to reshape and amplify light pulses, (2) connectors, allowing the fibers to be fixed to the transducers with a minimum possible of losses, and (3) couplings to allow the sending of information from one source to different sinks, etc.

B. PROBLEMS ENCOUNTERED

Once a simple point to point fiber optic data link has

been defined, a certain number of problems that will be encountered can be stated.

1. Coupling between Source and Fiber

Each specific source has its own characteristics, frequency, coherence or non coherence, size of the source, etc. Each fiber also has important characteristics, size, losses (that vary according to the frequency used), possibility of acceptance of light at its end, etc. To avoid excessive losses at this point, the properties and characteristics of source and fiber have to be made compatible.

2. Transmission of Light on the Fiber

When information is sent through a medium, the signal suffers some attenuation due to losses. In fiber optics, the problem of bending waveguides is enlarged. To avoid this loss fibers have to have specific shape.

3. Coupling Between Fiber and Detector

In the case of the light source and the fiber, problems of compatibility appear. The intensity of light at the receiver end has to be enough to drive the detector. The sensitivity of the detector is of great importance.

4. Coupling Between Fibers

When it is necessary to send information from one source to many different receivers, the problem of coupling

light arises. Up to now, the losses in these couplings are very high.

C. CHARACTERISTICS OF LIGHT

To better understand the problems related to the creation, transmission and detection of light, it is necessary to know what light is and what its characteristics and properties are.

Man knows that light exists because he senses it. In a general form it is possible to define light as a kind of radiant electromagnetic energy that can be detected by the human eye. The human eye can detect a wide range of light frequencies with higher and lower limits. The limits of the visible spectrum are: the ultraviolet, the higher limit and the infrared, the lower limit.

The nature of light can be interpreted in two different ways. One way is related to its electromagnetic characteristics, which helps in the understanding of its behavior in a transmission medium. The second, in which light is considered to be formed of certain particles, called photons, is an important concept related to the creation and detection of light.

1. Propagation

A basic property of light is its capability to propagate, to move from place to place. Due to the characteristics of the medium through which it propagates, the intensity of light decreases. This means that light intensity suffers an attenuation, the magnitude of which

will determine the distance at which a specific source may be detected.

2. Frequence, Wavelength and Phase

The transmission of light, which is generally characterized by the frequency of its electromagnetic waves, can be mathematically represented by

where 'x' corresponds to a distance from the source at a time 't', 'l' is the wavelength of the light, that measures the distance over which the intensity repeats its value as it moves along the direction of the beam, which in time corresponds to a time 'p'. The expression enclosed by parenthesis is known as the phase of the wave, that can be visualized as the instantaneous angle of the vector after a time 't'.

Wavelength and frequency are related in the sense that their product will be the speed of the light in the medium.

The frequency of the visible spectrum of light goes from 3.4×10^{14} hertz (cycles per second) to 7.7×10^{14} hertz, corresponding respectively to wavelengths of 7,800 to 3,900 Angstroms when it travels through air.

3. Interference

If two light waves overlap in a region of the space

at the same time, the total light intensity is not always the sum of the intensities of both waves but a different quantity that can be larger or smaller than the sum. This addition is governed by the respective phases of both waves, which in turn determine the value of the intensity cf the light at that point. The phase of the light depends on the length of the path travelled from the source. Different paths imply different times of propagation and if light from the same source reaches a point after travelling through two different paths, they will interfere and depending on their phases will increase or decrease its intensity.

4. Absorption and Scattering

As light moves through a medium, some of its energy is lost through excitation of atcms and eventually changed into heat. This absorption depends largely on the wavelength of the light and the chemical characteristics of the medium through which it travels. The intensity of light transmitted decreases exponentially with the distance travelled.

Scattering is the redirection of light when it falls into irregularities of the medium. It depends on the physical characteristics of the medium instead of the chemical ones which affect the absorption. This redirection is made in a random mode, decreasing the intensity of the light.

5. Reflection and Refraction

When a beam of light traveling through a medium reaches a boundary with another medium of different characteristics, some of the light will be reflected, that

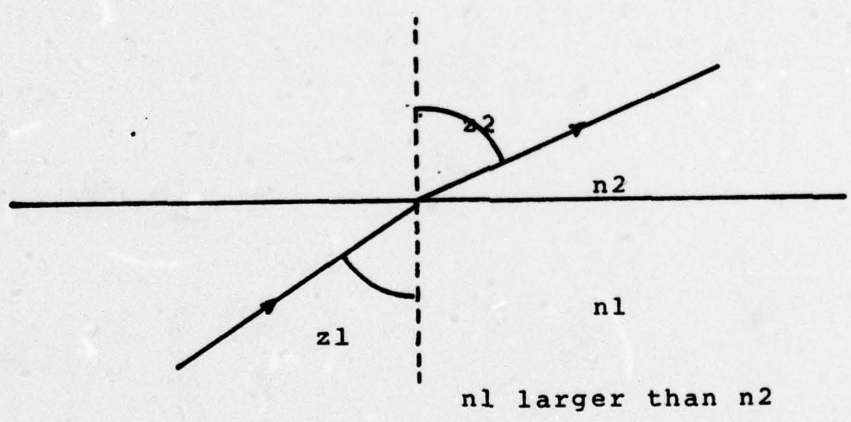
is, returned backwards into its original medium, and some will refract or traverse through that boundary.

The relative amount of light reflected and refracted depends on two characteristics, one, the angle at which light reaches the boundary and two, the refractive indices of both media.

The refractive index is a ratio that measures the speed of light in the medium related to that in the vacuum, which is considered to have a value of 1.0. Glass fibers usually have a value of 1.5 approximately.

The light which traverses the boundary, generally does not continue moving in the same direction. This bending of the beam, is governed by the specific refractive indices of both media.

Snell stated that this deviation of the beam depends both on the refractive indices and on the incidence angle as can be observed in Figure 1. He stated that: if n1 and n2 are the respective refractive indices of both media and z1 and z2 the angles the beam forms with the perpendicular to the boundary, then the phenomenon of the internal reflection occurs when the incidence angle is large enough to make z2 equal to 90 degrees. For angles z1 greater than this limiting angle the beam does not exist in the second medium, and is reflected into medium one with the same angle of incidence, z1.



$$\frac{n1}{n2} = \frac{\sin z2}{\sin z1}$$

Figure 1 - REFRACTION OF LIGHT

As the value of the respective refractive indices changes, so does the limit angle of incidence. If they are close, the limit angle will be large and if they differ greatly the angle will be small.

III. COMPONENTS

A. FIBER OPTICS

Based on the previously mentioned characteristics of light, the properties and the mechanism of fiber optic communication systems will be explained to achieve a deeper understanding of their properties.

1. Reflective Fibers

Propagation depends on the characteristics of the medium which in turn can be characterized by the medium's refractive index. Depending on the medium's value, light will travel through the medium at different speeds.

Another factor that affects the propagation speed is the frequency of the light itself. Light is composed of different frequencies and will travel through the fibers at the speed of the respective frequencies of the light's components, creating a difference in propagation because higher frequencies travel at slower speeds than the lower ones.

Reflection of light at a boundary depends on the angle at which light falls on the boundary. If the angle is smaller than the limit angle of incidence, light will not be reflected and will be lost. Refraction of the light is the bending of the beams according to the changes of refractive

index of the medium through which light travels.

If one of the extremes of a glass rod is illuminated by a light, a certain number of rays will enter it. The amount of light gathered depends on the numerical aperture of the fiber and its acceptance angle.

Acceptance angle is the angle that entering rays form with the axis of the fiber. The rays entering the fiber change their direction. The maximum value of that angle is limited by the limit angle of incidence of rays at the internal boundaries of the fiber. If the value of the angle the rays form with the axis of the fiber is larger than the value of the acceptance angle, the rays will fall into the interior boundary with an angle larger than the limit angle of incidence and will be lost (Fig. 2).

Numerical aperture is a factor used to measure the light collecting ability of the fiber. The factor depends on the refractive index of the medium external to the fiber as well as the acceptance angle. It can be seen that the acceptance angle depends on the limit angle of incidence at the interior of the fiber. The numerical aperture will depend on the refractive indices of the media forming the reflecting boundary inside the fiber.

The values of the numerical aperture are always less than 1. A value of 1 will imply that a fiber can accept 180 degrees of radiation of light from a source.

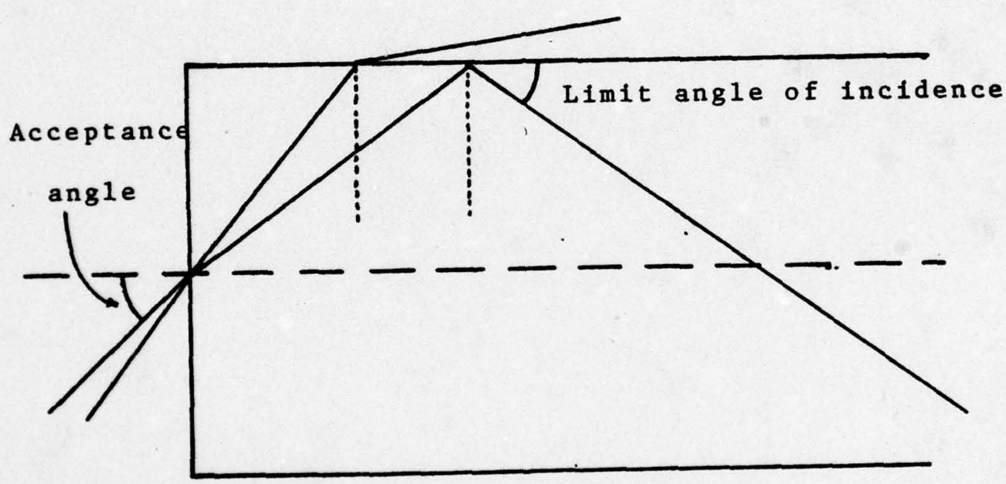


Figure 2 - ACCEPTANCE ANGLE

Those light rays which fall into the fiber with a small angle of incidence will be reflected on the sides of the rod and the rays will travel through the rod following different paths. Figure 3 shows that if the diameter of the rod is reduced, the number of rays entering the fiber will be reduced, decreasing the number of different paths and reducing the difference in the time that different rays take to reach a point a certain distance in the fiber. If the diameter of the fiber is further reduced, a point will be reached at which light travelling through the fiber will follow only one path. The light will reach the end without any difference in time between different rays, because there is only one ray. When the diameter of the rod is of the size of the wavelength of one of the components of light, only this component will propagate.

It can be seen that an impulse of light will propagate differently depending on the diameter of the fiber and the different frequencies of the components of the light. If the diameter is larger, the impulse at the other end will be wider than the impulse when it was created because the rays and frequency components will arrive at different times (Fig. 4).

The difference in time at the arrival is a measure of the broadening of the pulse and can be used as a measure of the speed of transfering information. This difference is measured in nanoseconds per unit of distance. The time between impulses at the sending end must be long enough not to mix two impulses at the receiving end because of the broadening of the impulses.

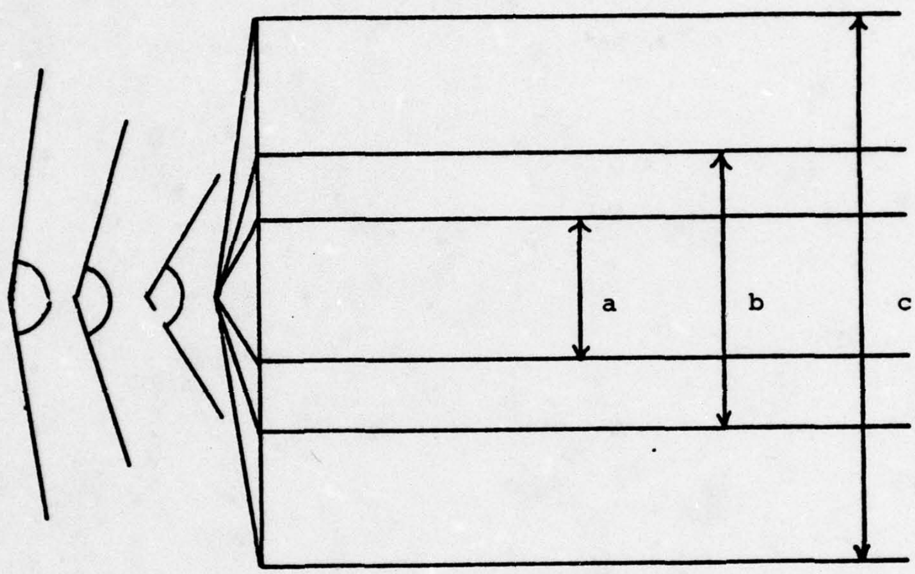


Figure 3 - EFFECT DUE TO THE DECREASE OF THE FIBER DIAMETER

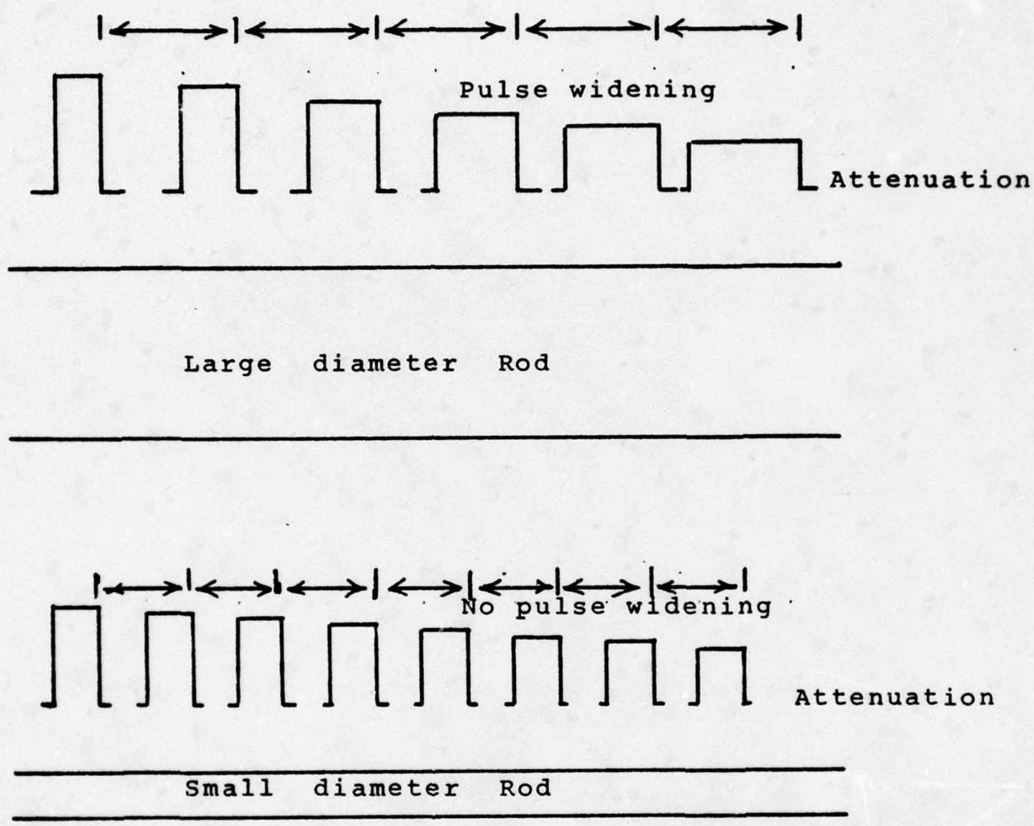


Figure 4 - PULSE BROADENING AND ATTENUATION ON DIFFERENT DIAMETER FIBERS

On the other hand if this diameter is small, only a few rays, or conceptually only one will propagate and the pulse will maintain its width during the entire length.

To have an efficient link, we will use different classes of light. With a large diameter, incoherent light can be used and as it will propagate in many directions, the pulse will be broad and a low speed of propagation will result. With a small diameter coherent sources which create light in a very narrow angle should be used.

The capacity to transfer information is sensitive to the diameter of the fiber because the variation in pulse width is large. In Fig.4 appear two fibers with different diameters and pulses at different points of the line. In the first case, large diameter and non coherent light, the moment at which we can send a new impulse is limited by the broadening of the impulse at the receiver end. In the second, the receiver observes no change in the pulse width and therefore it is possible to switch faster.

In optical fiber technology the two kinds of fibers are called multimode step index and single mode step index fibers, because the first allows many modes to propagate and the second only allows one mode.

2. Refractive Fibers

If we vary the refractive index in the rod according to its distance to the axis of the fiber, making the index value smaller as its distance from the axis increases, the different rays of light entering the fiber at the rods end with angles different than zero, will bend continuously

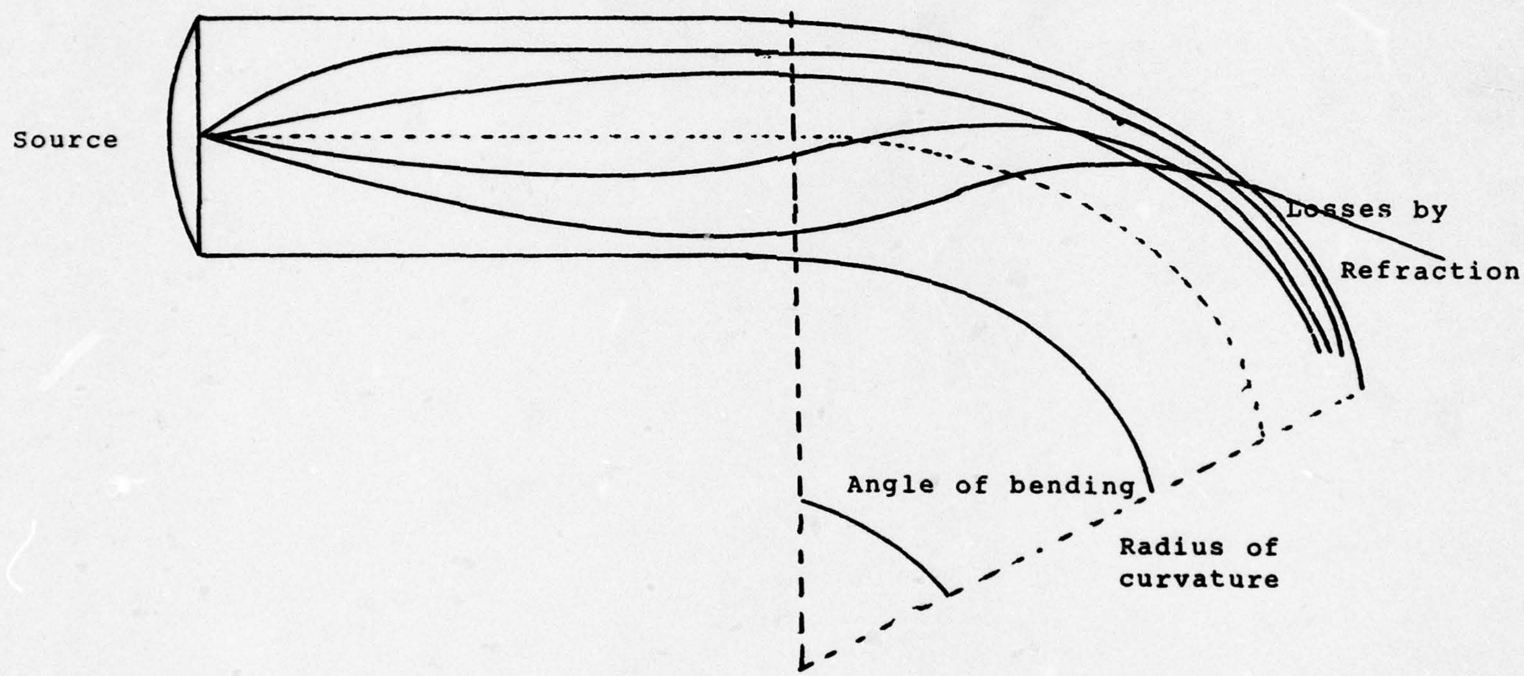


Figure 5 - GRADEX INDEX FIBER, EFFECTS OF BENDINGS

until they find a layer with constant refractive index. After being in that layer, any discontinuity or bending of the rod will bend the rays again. As can be seen in figure 5, if the rod is bent downward, the rays above the axis will encounter smaller refractive indices and will bend downward, trying to find a new layer where they propagate in a straight line. Rays below the axis in the figure, will find larger refractive indexes and will be forced to cross the axis, after which they will encounter decreasing refractive indexes and will bend downward trying to find a layer of constant refractive index. Longitudinal variations of the index will create similar behavior.

In this medium, modes of light will propagate through different paths but the bendings will be smoothed when compared with those in a reflective fiber. Thus path variations will be smaller than those in a multimode step index fiber, and the width increase of the impulse at the receiver end of the fiber will be smaller, allowing higher speeds of transmission on the line.

Light when travelling in media of lower refractive indices travels faster, thus the modes that travel through the longer paths, will travel faster. This tends to give the same delay for different modes of propagation which results in a smaller distortion of the pulse.

The width of the pulse will be largely influenced by bending the fiber. If the fiber lies in a straight line, the speed of transmission of the light in the fiber will be close to that of the single mode fiber. If it bends continuously, the speed will be close to that of the multimode fiber.

This kind of fiber is called 'Multimode Gradex Index Fiber'.

3. Fiber Optic Bundle

Fiber optic bundles, as its name implies, are formed by a number of fibers grouped together to form a single optical path. They are tougher than the single fibers and are coupled to sources and receivers with a more radiant surface.

There exists a trade off in using bundles or single fibers. With the bundles, there is a protection against the breakage that will interrupt the transmission. This is because redundancy is provided by using many fibers. The single fiber has the advantage of its low cost, but has to be protected from stress because it is fragile. Another difference is the cost of connectors which will be seen in a later section.

4. Losses

It has been shown that light travels through different paths, but nothing was said about losses. The properties of light that govern the mechanism of light transmission are propagation, reflection and refraction. The phenomenon of loss is explained based on absorption, scattering and refraction. The influence that these three characteristics have over losses will be discussed next.

In the preceeding paragraph the light kept in the interior of the fiber was studied. These rays of light travelling through the fiber are attenuated because of the absorption. As electromagnetic radiation create fields which collide over the metallic impurities of the fiber, Ions of Iron (Fe), Copper (Cu), Cobalt (Co) and other metals

have absorption bands at light frequency. Water molecules also cause a large absorption. Depending on the absorption bands, light is more or less attenuated. As this occurs at specific frequencies depending on the ions, frequencies of light spectrum have different attenuations.

Corning Glass researchers, obtained the graph in the figure 6.

In the figure, the different levels of attenuation of light dependent on its wavelength are indicated. The peaks of attenuation occur at wavelenghts of 0.72 micrometer due to impurities in that band. (These impurities are principally due to ions of copper), and at 0.95 micrometers due to water molecules.

The rays of light that leave the fiber because they are refracted are another source of loss. This scattering can be divided into two different classes, one called Raleigh scattering is due to nonhomogenities of the medium much smaller than the wavelength of light.

If the surface of the fiber is analyzed using measurements of the order of magnitude of the wavelength of light, its roughness will be apparent. This roughness appears in the form of bubbles and cracks in the surface of the fiber. This will change the direction of the rays of light from their paths and these rays will be lost. The above losses can be called inherent to the fiber.

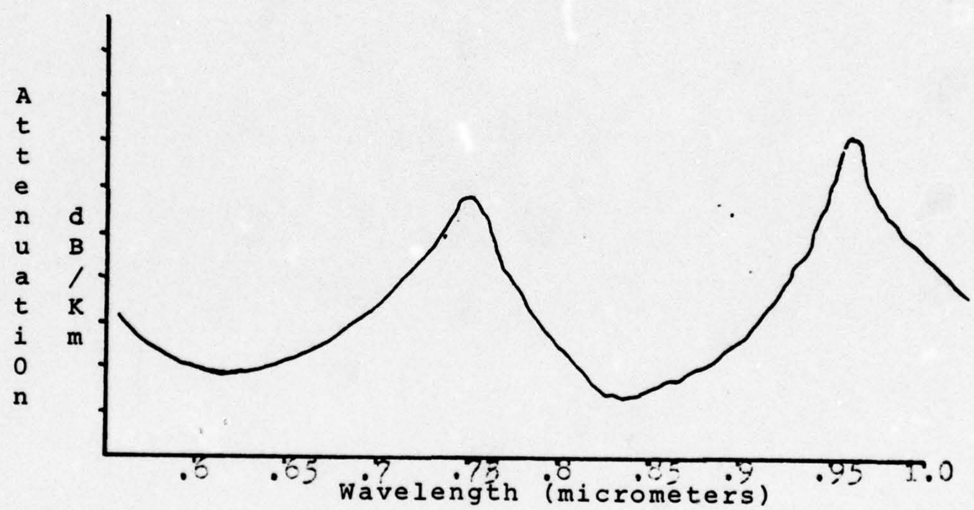


Figure 6 - ATTENUATION VERSUS WAVELENGHT OF LIGHT

Another loss produced by the refraction may be called external. These are due to bends in the fiber. These losses are proportional to the radius of curvature of the bend. The smaller the radius, the higher the losses.

The measurement of the losses in the fiber are made in decibels per unit of distance, generally dB/km..

$$\text{Losses} = 10 \text{ Log } \frac{P_{in}}{P_{out}} .$$

The approximate value of the losses due to different mechanisms, measured at Bell Labs in a fiber of 16 dB/km are the following: 4 dB/km attributed to Raleigh scattering; from 6 to 9 dB/km to scattering due to defects of the fiber and the rest due to absorption. This is only an example. Different systems of fabrication can vary this proportion substantially.

In conclusion, it can be said that varying the chemical composition of the fiber by extracting its different impurities, fibers with different attenuations to different frequencies can be built. This method can be a great advantage to the making of compatible light sources and fibers.

5. Cladding

To complete the study of the fiber, the effect and the need of the cladding has to be explained.

It was mentioned previously that the effect on the direction of light crossing a boundary between two media with different refractive indices is related to the values of such indices, but nothing was said about the effect on the propagation losses.

If the difference in the refractive indices is large, as in the case of the air and fiber, the limit angle of incidence will have a value of approximately 45 degrees. As this difference diminishes, the value of n^2/n^1 approaches small values. This has an important effect: less rays will propagate and the width of the pulse will be smaller and the transfer of information per unit time can be much higher.

Since light is an electromagnetic phenomenon, when rays reflect on the boundaries of the fiber, they create electromagnetic fields external to the fiber. Any variation in that external medium, will create nonlinearities which will result in higher losses. If the fiber is covered with a substance with constant refractive index and is such that the electromagnetic field due to light does not extend beyond the layer, the external variations will not affect the propagation of light.

Thus, it would be advantageous to cover the fiber with a substance with a refractive index slightly smaller than that of the fiber and with enough thickness to eliminate the electromagnetic field. This new protective layer is called Cladding. Generally this cladding is thicker than neccessary for ease of handling. Its minimum thickness must be of the order of several wavelengths.

B. SOURCES

1. General

If one compares the advances accomplished in communications with the actual state of the art of light sources, it can be seen that the optic communication field today is not developed enough and that there is still a long way to go. At this time only very specific things can be done, though their importance is enormous.

For high performance, a fiber optics communication system depends principally on the carrier. However, tc have a successful system, the light generator has to be reliable, economically worthwhile and fiber compatible. The light generator's reliability can be measured using its probable life span, which in some cases will affect its application. Also, reliability is related to economic advantages or disadvantages.

When designing an optical communications system, the designer has to compromise between the characteristics of sources and those of fiber optics.

Since the losses in light intensity are appreciable when light crosses boundaries between media with different refraction indices, an important problem is the loss at the coupling between the light source and the fiber.

Because the communications system has to be consistent, sources must be capable of managing the largest amount of information that the fiber can accept. The

emission response time delay limits the response of the source to changes at its input. This limits the speed at which the source can be driven by the injected current.

When light is modulated externally to the source, the source is continually emitting a constant intensity of light. The time delay of external modulation then governs the rate of data transmission.

When fibers were studied, it was said that they react differently to different frequencies, although to avoid high losses, sources have to emit light at the frequencies best suited to the fiber. Also, it was said, that the numerical aperture is a characteristic that measures the collecting ability of the fiber. Because of this characteristic, to avoid losses, the source has to emit light capable of being easily accepted by the fiber. The use of incoherent light with a single mode fiber appears to be nonsense. Incoherent sources are better suited to multimode fibers and coherent sources to single mode fibers.

A difficult problem to solve is that of the alignment of the source to the fiber. Fibers are extraordinarily thin, therefore the pointing of light to the fibers is difficult and the use of multimode fibers instead of single mode ones is preferable.

The use of cladding limits the acceptance angle of the fiber to about 8 degrees. This means that the angle of emission of the source has to be of approximately the same magnitude in order not to create an inefficient coupling.

2. Semiconductor Light Emitting Phenomenon

The current sources are light emitting diodes and

lasers. Basic to their operation is the semiconductor light emitting phenomenon. This phencmenon can be described as the recombination of electrons and holes in a forward biased junction releases a certain amount of energy equal to the energy gap between the valence and the conduction band of the atoms. This energy released is given off in different forms, depending on the materials that form that junction, which in the case of light emission determines the wavelength of the emitted light.

A material used to produce light instead of heat, as silicon and germanium do, is a compound of Gallium (Ga) and Arsenic (As). This compound, Gallium Arsenide, is the oldest and most used semiconductor material for LEDs and injection lasers.

Recently, different metals, aluminium and zinc, were added to this compound: the first controls the frequency of the emitted light, the second increases the life of the source.

3. Light Emitting Diodes

The light emitted by an LED is incoherent. Two considerations are of importance about this source. One, the intensity of the emission, measured in watts of optical power radiated into a solid angle per unit of emitting surface (Fig. 7). The second is the emission response time, which limits the speed of transfering information. The best LED will be the one with the highest radiated power and fast response time. Up to now the only limiting factor in LEDs usage is its life expectancy.

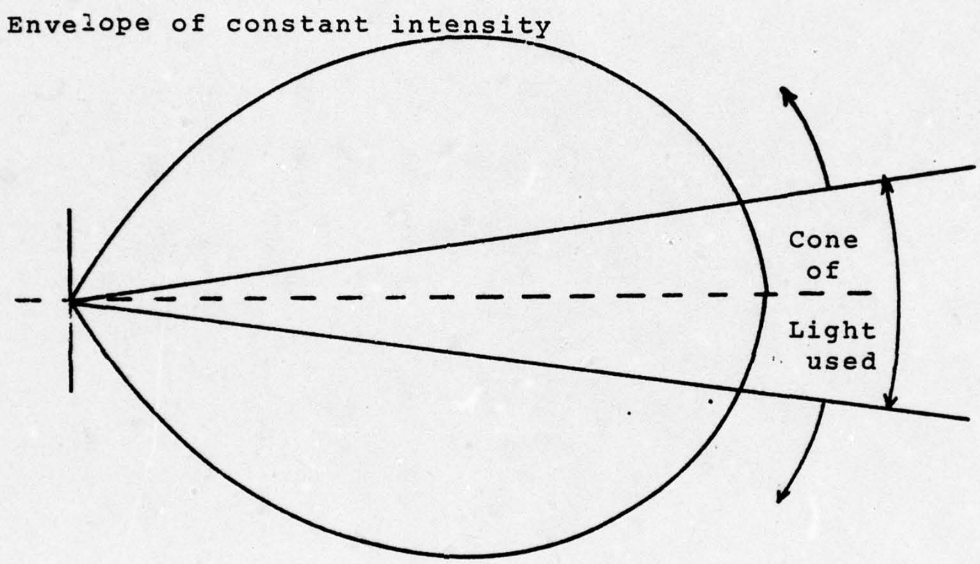


Figure 7 - RADIATION BEAM OF A LED

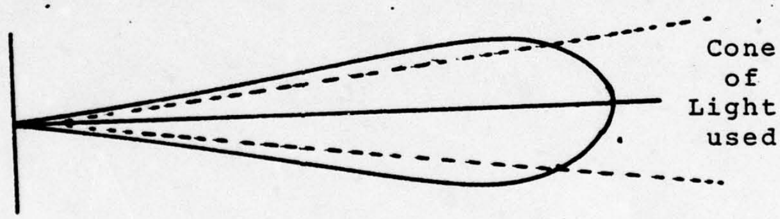


Figure 8 - RADIATION BEAM OF A LASER

The coupling efficiency of the LEDs is very poor with fibers because of the large angle of emission of this incoherent source, whose wavelength varies between 0.9 and 0.93 micrometers. The power output of the LED is very small, about a maximum of a hundreds milliwatts. Because the LEDs light intensity responds almost linearly to the current that drives it, it is suitable to be continuously modulated and analog modulations are possible.

4. Lasers

The light emitted by a laser is coherent. The production of light in a laser instead of being spontaneous as it is with the LEDs, has to be stimulated. Originally, when low levels of current are applied to a laser, it behaves like an LED. As this level is increased over a limit or threshold, a phenomenon that can be compared with the avalanche phenomenon in the semiconductor occurs. The light created originally, falling into the electrons, stimulates the recombination, producing a high increase in power. This light is highly directed and confined as if it were focused by a parabolic mirror.

The injection laser emits light in a very small solid angle (Fig. 8) and its power output can have peaks of many watts. Since this is a high power for the very small chips, that lasers are, problems of cooling arise. These high power pulses can only have a very small duration in order not to damage tha laser. The laser's average power output is slightly larger than that of the LEDs.

The laser matching to the fiber is more efficient than the matching of LEDs, and its wavelength is between 0.7 and 0.9 micrometers.

Injection lasers can also be easily modulated with input current but its efficiency is not as good as with LEDs, because they react differently to specific light frequencies. Modulation rates up to 2 Gbits/sec are possible .

A laser's lifetime is shorter than that of the LEDs but can be improved if they are used with some type of pulse modulation.

C. DETECTORS

1. General

Fiber optics communications require light detectors with different characteristics. Light detectors have to be sensitive to light levels and to the wavelength of such light, which in turn depends on the source being used. They have to be capable of accepting the modulation rates of the light being received.

Two important problems are the match between the fiber and the photo diode and between the photo diode and its amplifier. Many implementations include the photo diode in the integrated semiconductor amplifier.

2. Light Detection Phenomenon

If light falls into a specific metallic surface, electrons are liberated. If an electrostatic field is created between this piece of metal and another one further away, electrons will flow between them thus creating an

electric current. The intensity of this electric current is proportional to the number of electrons liberated by the metal, which in turn depends on the amount of light the metal receives. Depending also on the wavelength of the light, photons have different amount of energy. The longer the wavelength, the less the energy of the photons. Though the longer the wavelength the more difficult it is to liberate the photons. The minimum energy needed to liberate a photon, defines a cut off wavelength beyond which no photoemission can occur.

The receiving surfaces were recently made of semiconductor materials containing Ga and As, the same as ones used in the fabrication of sources. When light falls into a p-n junction to which an electric field has been applied, each electron recombines with a hole, creating a flow of current in the junction.

3. PIN Photo Diode

The three letters P, I, N, stand for P material, Intrinsic material and N material. As its name implies, this photo diode is a modification of a P-N junction in which a certain amount of intrinsic material is introduced between the P and N layers, to increase the frequency response due to the lower capacitance of the diode. This capacitance is also lowered because of the reverse polarization of the diode. The P layer is made very thin to reduce the capacity. The efficiency, or number of electrons produced by each photon is enhanced.

The PIN photo diode is the photo detector used most in today's industry. Its response time is of the order of nanoseconds which allows it to accept high rates of modulation. Its maximum sensitivity is to light, with

wavelengths between 0.85 and 0.95 micrometers. This matches it with the fibers for which the low loss region is in the lower margin of these wavelengths.

4. Silicon Avalanche Photo Diode

This photo diode is similar to the PIN but is used with high reverse voltages to achieve a gain. The initially created electrons are accelerated and create new electron hole pairs amplifying the current. This amplification acts also on the noise, amplifying it. Because of this amplification, avalanche photo diodes are more sensitive to low light levels than the PIN photo diodes.

The construction of avalanche photo diodes is more difficult than that of the PIN and they need higher voltages, which in many cases requires the use of cooling mechanisms.

Avalanche photodiodes can be used with frequencies over 1 Mhz. Because of its need for a high voltage power supply, it is better suited for digital rather than analog communications, because in digital communications the absolute levels of the signal are not important.

D. SECONDARY DEVICES

1. Data Bus

Large scale integration, and the microprocessor in particular, has revolutionized digital systems. The development of optical links for communications, suggests

that they could be used between integrated circuits, to eliminate the bottleneck created by the connection technology, so that LSI technology can be further exploited.

The links between integrated circuits are very complicated and the replacement of wires by optical links would, initially, be very costly. Instead of this, a different approach has to be developed. This approach consists of using Data Buses, with the capability for time multiplexing the information that is sent between each integrated circuit or module. Because the bandwidth of the optical link is large enough, different time slots can be used to execute the necessary transfers. The time slices are controlled by a microcontroller.

The A-7 ALOFT project was established to demonstrate that the original point to point wired data communications system may be replaced by a fiber optic interface, without degradation of performance. In a system like this, light has to be tapped at intermediate points along the data bus, allowing the flow of information in both directions without appreciable losses.

MIL-STD-1553A, defines the requirements of digital, command response, and time division multiplex data bus, which also specifies the interfaces and the concept of information flow on the data bus.

Although these specifications were initially created to fulfill a hole in pure electronic data bus specifications and to establish uniform requirements for multiplex data bus techniques to be utilized on board aircraft, many of its requirements are perfectly valid and applicable to fiber optic data buses.

2. Couplings

To allow optical communications between a source and several different terminals, light signals must be split at intermediate points along the fiber. Such couplings imply losses. The losses in the system are proportional to the number of couplings.

The need for couplings is apparent when data buses are used as part of distributed networks. When used in this kind of applications two kinds of couplings are employed, T-couplings and 'star' couplings.

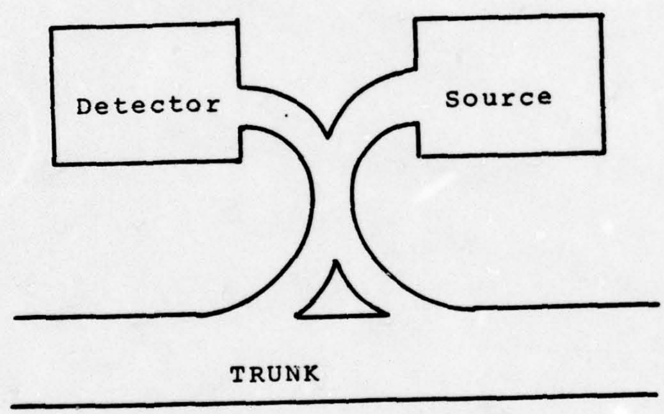


Figure 9 - T-COUPLING

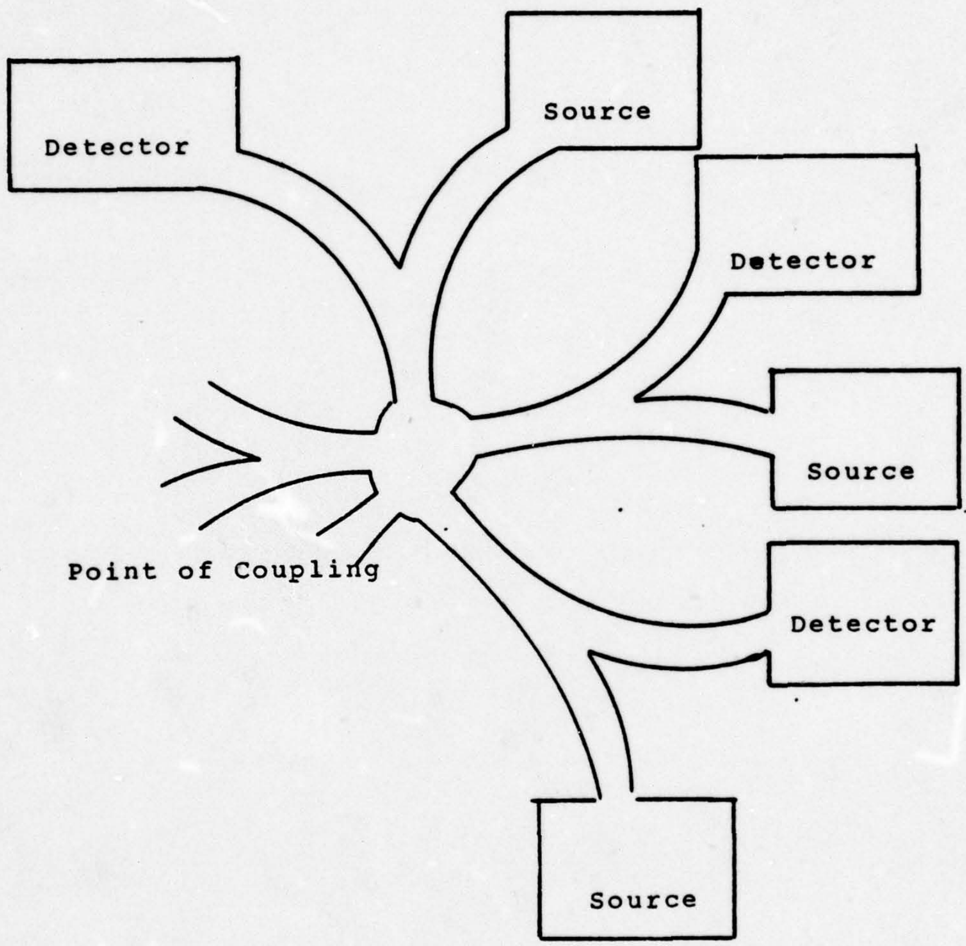


Figure 10 - STAR COUPLING

A T-coupling is one in which each one of the terminals is linked to a general trunk line, allowing the flow of information to and from such a principal trunk (Fig. 10).

A 'Star' coupling is one in which all the terminals are linked together at a point at which each part of the data bus is connected to all others (Fig. 11).

The main difference between the systems is the distribution of losses. In the star coupler, the losses are incurred at a point and are always uniform, independently of which one of the terminals is considered.

In the T-coupling, the optical paths are different with a different number of terminals and light power decreases as the signal travels through more couplings. The trunkline concept creates differences in the intensity received by each detector. This will require the designer to use detectors with a high dynamic range. In the case of the Star coupler, this problem is avoided, because the signallevel is nearly constant. Star couplings have also the advantage of less loss in total although the total length of the cable is greater.

3. Connectors

Two different kinds of connectors are used in Fiber Optics: end of the line connectors (to match the fiber to the source or receiver) and cable to cable connectors to match two fibers at their ends.

In order to be practical, a connection must not require special tools that are only available during

assembly.

a. Sources of Losses

When matching the fiber to the source or the receiver many different reasons for losses appear: lateral misalignment, gap between the fiber and the front end, angular misalignment, and the fiber itself terminating.

When the match is between two fibers the same problems occur, with exception of the gap between fiber and front end.

The efficiency of the coupling depends on how well the fiber is matched to either the detector or the source. The characteristics of the elements involved have to be accounted for. For example, an edge emitting laser produces a beam of light with a doughnut shape and if the fiber is placed in the middle of it, no light will be coupled into it. In a single fiber, a misalignment between the axis of the fiber and the front end equal to about half of the diameter of the core causes a loss of approximately 4dB. If this misalignment increases, the losses will increase geometrically (Fig. 12).

Angular misalignments are more critical on the source to fiber connector because they directly affect the power transfer. Generally the sources create a beam with larger intensity on its axis, as can be seen in fig. 13.

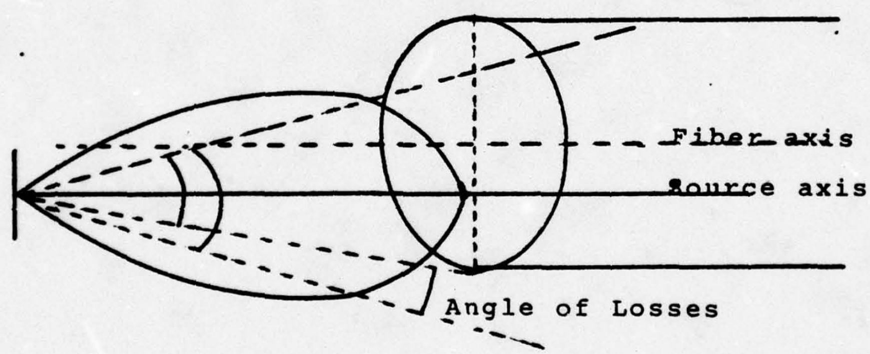


Figure 11 - LATERAL MISALIGNMENT

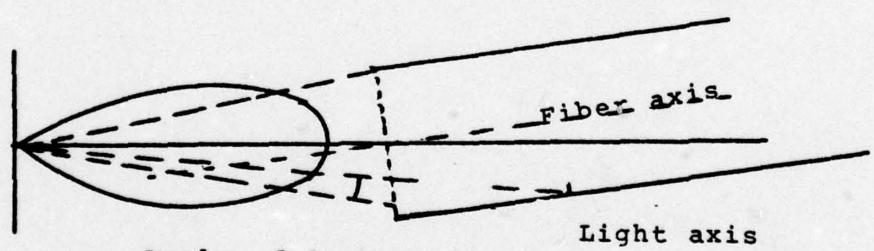


Figure 12 - ANGULAR MISALIGNMENT

If a misalignment between the fiber axis and the beam axis occurs, the losses increase proportionately. An angular misalignment of plus or minus one degree for fiber bundles and half of that for a single fiber results in losses between 0.1 and 0.2dB. Obviously single fiber couplings are more critical.

In separable connectors, this misalignment is a very important factor to be noted. In fiber to fiber connectors, this source of loss does not apply. It is important that fiber and front end be as close as possible but without touching each other because repeated matches and vibrations will scratch the fiber termination increasing the losses for this reason. A separation of about 10 per cent of the diameter of the fiber will create a loss of about 0.2 dB. This loss will increase near logarithmically with the increase in separation. If this separation is half of the diameter the losses are about 6dB.

The loss characteristics of these gaps vary slightly with the numerical aperture of the fiber. The larger the numerical aperture, the smaller the loss because the fiber will accept the air scattered rays.

An imperfect termination will create a scattering of the rays of light, which will increase the losses. The fiber has to be terminated in a perfect cross section, chip free and flat. A simple polishing procedure can produce a good optical interface. Special tools are created by the fiber manufacturers.

b. Fiber to Fiber Connectors

This kind of connectors must be permanent. They are easier to make and have less loss than the ones that match the fibers and the front end. The most frequently used ones are made of a tube that conforms exactly to the outer diameter of both fibers. Both fiber ends after preparation are butted together in the tube. The tube ends are crimped into the coating of the fiber to keep the ends tight and motionless. Between both fiber ends a fluid is injected which has the same refractive index as the fiber. Typical losses in this kind of connectors average about 2 dB. These losses are usually called insertion losses.

c. End of Line Connectors

These connectors match the fiber to the front end. Since they can be disconnected they inherently have higher losses. When used with factory prepared ends in premeasured lengths of fiber, they are easy to install. This fiber preparation consists of making the ends of the fiber strong enough and suitable for fitting into the shell of the connector.

These end of line connectors can be divided into three categories according to their functions.

Single fiber connectors are very difficult to manufacture because of the problems of alignment. The small diameter of the fiber requires precise mechanical tolerances. Bundle connectors are less costly than the single fiber ones and the problem of misalignment is not so critical. Connectors that handle many different fiber optic

bundles are similar to a common multiwire connector.

E. MODULATION

Light modulation can be obtained directly in the source itself, or indirectly in a way external to the source. In the first case the information to be carried is associated with the current that drives the source. The characteristics of the source govern this kind of modulation.

Light emitting diodes with a linear input to output characteristic are appropriate for this kind of modulation. LEDs can be used with digital as well with analog modulation. In the case of digital signal transmission the driver is usually made of a high speed pulser which switches the diode ON and OFF.

Lasers can be also used in digital signal transmission. They have some difficulties because of their characteristics. Lasers are excited for currents higher than a certain threshold level. Since this level of current is highly dependent on temperature, they need a compensating circuit. Because of this possible variation on the threshold levels, lasers can be driven accidentally thus creating a new source of errors.

The indirect type of modulation is done using devices capable of externally modulating the light beam. The source is continually emitting and the beam intensity is varied according to the current information. Since this emission diminishes the life of the source, it is not widely used.

F. MULTIPLEXING

Because bandwidth of fiber optic communications is very large and allows very high transmission rates, some degree of multiplexing will be worthwhile. The type of multiplexing that can be used depends on the specific applications. The multiplexing of the different signals is done electronically before the source is driven. After passing the detector this signal is demultiplexed again. Because of this and because a multiplexed signal can be considered as a sole individual signal this problem has not been extensively studied.

Frequency division multiplex and time division multiplex are generally used. The ALOFT program used time division multiplexing. The choice between both is largely related to the kind of information transmitted. With analog information frequency division multiplexing appears to be preferable because of the burden to digitalize the information. In cases in which the information is digital, time division multiplexing is better. In the future, as there is a general trend to digitalize all kinds of information, time division multiplexing is likely to be extensively used.

G. CODES

Optical communications can easily accept many kinds of codes, because their characteristics are totally independent of the code used. Commercial applications make use of Telegraphic codes. Military applications use the code required in each case.

Military Standard for Aircraft Internal Time Division Multiplex (MIL-STD-1553A, 30 April 1975), specifies the data code to be used in avionics, namely the Manchester bi phase level.

This so called Manchester code has the advantage that it allows both data and clock to be combined in a self clccking wave form.This results in the savings in weight because significant hardware can be eliminated.

When applied to fiber optics, as in the ALOFT prcject, the optical interfaces have to convert this Manchester code into light pulses, to be sent through the line.

H. ERRORS AND DISTORTION

Any fiber optics communications link is subject to errors and distortion in the signals as a result of the non linearity of the losses. The most widely used measures of error are the Bit Error Rate (BER) and Signal to Noise Ratio (SNR).

1. Digital Links, (BER)

The most important performance parameter in a communications system using digital techniques, BER, is the ratio of the number of incorrect bits to the total number of bits received. This BER depends largely on the total link, that is, source, fiber couplings, etc. Generally BER's relation to losses and distortion parameters is not linear because there are points at which very small variations in the characteristics improve the BER radically. An example can be the following: In a specific link in which the signal

to noise ratio is about 20dB, an increase of 1 dB will improve the SNR from 10 to the minus 8 to about 10 to the minus 10. The factor that highly influences the bit error rate is the fiber itself. At the source, the possible distortion on impulses due to the rise and fall times, can be shortened by means of additional current spikes.

2. Analog Links (SNR)

In analog systems, Signal to Noise Ratio and Harmonic Distortion are very important measures of signal quality. The lack of linearity of the source, is the more important cause of this harmonic distortion.

IV. APPLICATIONS ENHANCED

A. GENERAL

Fiber optic communications appear on the market at a moment in which the world is envolved in a vanishing metallic resources. The use of fiber optics not only solves the problems related to the existence or non-existence of these resources, but enhanced a large number of applications because of its special characteristics. Improvements, discussed in a different section, are numerous and the original search for new and cheaper materials has changed into the enhancement of actual systems.

B. AVIONICS

Military applications, where advantages other than information transfer capabilities are critical, short and medium distance links, etc. will take advantage of this improvement. When signals in avionic environment are transferred electrically, an operational degradaticn and damage due to the susceptibility of the metallic conductors to electromagnetic interferences, cross talk, ground looping, and reflection affect also the system's operation. If an optical interface is used to transfer signals, information is transmitted through bundles of glass fibers or through single fibers. Because of the dielectric nature of the glass, the fibers are immune to electromagnetic

interference and are unaffected by electronic conduction problems. Because of this attribute, the high bandwidth capabilities, and the light weight of fiber optics cables, this method of communication has become very desirable.

Multiplexing reduces the number of signal paths and the complexity of cable connectors, but increases slightly the electronic hardware. This increase is compensated by the advantages previously noted. The resulting enhancement of the system's performance and the savings of space and weight make fiber optics technology highly important in avionic systems.

C. TELEPHONE NETWORKS

The decrease in losses achieved by fiber optics are making them usable in long distance applications. Communications systems would have enormous information carrying capabilities. Fiber optics passed in a few years from attenuations of 1000dB/m to 0.47 dB/km at the wavelength of 1.2 micrometers, as announced in 1976 by The Nippon Telegraph and Telephone in Japan. The breakdown of 20 dB/km was reached in 1968. 20 dB/km is approximately the loss incurred in the coaxial cables routinely used for long haul applications. Since the need for repeaters not only depends on the losses in the wire but also on the power transmitted, and on the sensitivity of the receiver, care has to be taken in not using the figure of 20dB/km as a comparison between both technologies, but only in its energy consumption. The repeaters in fiber optics may be spaced at a distance more than twice that of the repeaters in pure electronic communications. The best fiber previously produced was by Bell Laboratories, and had a minimum loss of 1.1dB/km. at 1.02 micrometers. In practice, fiber

attenuation may be in the region between 3 to 4 dB/km. Cables with attenuations between 10 and 30dB/km. are now manufactured.

A field demonstration of a 140 Mbits/sec digital optic system for a telephonic network is to be carried out in England, in the second half of 1977. The system which will have a length of 9 km. will have a repeater every 3 km. and will be capable of handling 1920 speech channels.

In France, La Compagnie Industriel Telegraphique (CIT) made a link to be used in the dialing network. The transmission speed is 2 Mbits/sec. It made use of LEDs and PIN photo diodes. The link is a cable of 18 fibers of 'multimode step index', 200 meters in length.

In USA, American Telephone and Telegraph (AT and T) has announced that a one and a half mile system carrying voice, data and video signals is being tested in Chicago. Bell Laboratories and AT and T in cooperation with the Illinois Bell and Western Electric Co. will test two underground repeaterless sections. A single pair of fibers will carry 576 simultaneous conversations or an equivalent mix of voice or data. Separate fiber pairs will carry Videophone, meeting service video signals.

D. INTER-OFFICE TRUNKS

Bell Laboratories assembled a fiber optic communications system aimed to inter-office trunk applications in urban areas. The design uses conventional electronics to amplify, reshape, and regenerate the digital signal. The sources and detectors this system utilizes are Ga, Al, As injection

lasers and photo diodes.

An experimental fiber optics trunk was tested in Atlanta, Georgia in January of 1976.

E. SUMMARY OF MILITARY APPLICATIONS

1. Shipboard Applications

A system of internal communications is working now for three years in the aircraft carrier, '*Kitty Hawk*'.

The Royal Navy (UK) has a four channel link used on board in a large variety of applications.

The U.S. Navy is testing a fiber optic link aboard one submarine to replace heavy copper wiring with lighter, interference free cables.

A 52 channel analog link for a sonar array is being installed by the New London Laboratory of the Naval Underwater systems Center in New London, Connecticut.

Distributed Microcomputer Networks in Integrated Weapon systems are being tested in Holland.

2. Aircraft Applications

The well known ALOFT project, (Airborne light Optical Fiber Technology), was the beginning of a series of fiber optics applications to Aircraft.

The B-1 bomber was to use in its components different fiber optics links.

In England, the Marconi Company has studied the realization of a fiber optics system to be installed on the YC-14, a military transport VSTOL.

In France La Societe telegraphique et Telephonique (STTA) installed on board of a Nord 262 a fiber optics system to evaluate it on different environments. The speed of transmission in this system is about 5 Mbits/sec.

3. Tactical Applications

The U. S. Army is replacing copper wire with fiber optics in its tactical communications systems. Up to now, the Army has replaced the twin coaxial cable used for long haul communications and the 26 pair cable used in the local distribution systems at the Army Electronic's Command's Communications Automatic Data Processing Laboratory at Fort Monmoth, N. J.

4. Current Equipment and Manufacturers

The appendices of this thesis contain both a list of current equipment and current manufacturers of this equipment. Appendix A lists current types of fibers, Appendix B lists current types of sources and sinks, and Appendix C lists manufacturers by the components which they produce.

V. ECONOMIC ANALYSIS

A. GENERAL

The economic analysis of fiber optics, has to be included in the whole Economic Analysis of each application, involving the determination of the cost and effectiveness of the different alternatives. As Fiber Optics appear to be a substitute for conventional wiring, all alternatives have to be studied.

Effectiveness, or the extent of success achieved by a system in accomplishing a set of objectives, is a parameter very difficult to measure. this can be done in a relative fashion, comparing the output of the different alternatives.

There are three different criteria to select or recommend the selected alternative. (1) Fix the effectiveness, and select the alternative that achieves the fixed level of effectiveness at the lowest cost. (2) Fix the cost and select the alternative which is likely to produce the higher effectiveness. (3) Vary the cost and study the variations of effectiveness, building some kind of relationship that will help the decision maker in the selection of the best alternative.

To decide which one of these three criteria to utilize in the case of the fiber optics communications, the ratio between the cost of the fiber optic part of the system and the total cost of the system has to be studied. As a result,

it appears to be more appropriate for a fixed cost study when this ratio is very high and variations on the cost of the optics govern largely the total cost, and the rescurces allocated do not allow large variations. This can be the case of a fiber optic telephone network. On the other side, when this ratio is small allowing variations on the cost that do not involve large changes on the total resources allocated, a fixed effectiveness criterion is more appropriate. In this initial period of application of this new technology, in which only a small part of the system is to be changed, the fixed effectiveness criterion is more appropriate. In the future when the applications of fiber optics technology are broad, the fixed cost criterion will be applicable.

The Economic Analysis of the fiber optics is intended to be carried out by analyzing the Design of the optical system and the cost of the required materials. Then, a coefficient will be applied in each case depending on the different characteristics which will vary its effectiveness.

B. OBJECTIVE

The primary objective of this study is to establish the economic feasibility of incorporating fiber optics technology in these systems which presently use pure electronic tecniques and conventional wiring.

To some extent the application of fiber optics to a specific project, can change the total design of that project. This case in not studied because it falls out of the scope of this thesis.

C. ALTERNATIVES

The alternatives of this analysis are: One, to continue the use of conventional systems using electronic equipment and conventional wiring, the second use Fiber Optics technology.

D. COST ANALYSIS

In a situation like this, the analysis has to include the whole life cycle cost (LCC) for both technolcgies, Conventional Wiring and Fiber Optics.

The life cycle cost of each alternative visualized as:

Life cost of the system	=	Res. and Developm. cost	+	Procur. cost	+	Operat. and Maint.	-	Estim. Salvage cost.

The comparison between the alternatives has to be consistent. It is more important to have consistence in the comparison than precision of the estimate.

Sunk costs should be excluded. Sunk costs are those resources that have been expended prior to the study and which can not be recovered. Sometimes there are costs that are difficult to meassure and can not be quantified.

Because fiber optics technology is in its beginnings, the availability of cost data in that field is very limited. Because of this fact, many of the costs are 'best estimates' based on available data. In order to facilitate making such estimates, Ref. 10 establishes that a ccst can be fixed, applying a coefficient to that cost of conventional wiring

on a element by element basis.

$$\begin{matrix}\text{Cost}\\ \text{of}\\ \text{Fiber Optics}\end{matrix} = \text{Coefficient} * \begin{matrix}\text{Cost}\\ \text{of}\\ \text{Conventional Wiring}\end{matrix}$$

The coefficients are the estimated ratic between the cost of the fiber optics and the cost of the conventional wiring. This coefficient is calculated using a technique called 'Delphi' which consists in a polling of experts actually accomplishing tasks similar to the one questioned. These experts file a questionaire which asks many questions related to those costs, and from these estimates the coefficient is formulated.

The cost study explained here is that of the ALOFT project as is given in detail in Ref. 10.

The values stated are percentages of the total cost of the system of conventional wiring.

1. <u>Reseach and Development</u>

Research and Development costs for conventional wiring includes only two elements of cost: Engineering and Fabrication. According to ref. 10 which uses data collected during the ALOFT demonstration, the data is as follows:

Elements of Cost	% of Cost
Engineering	0.00043
Fabrication	0.01117
Total R. and D.	0.01160

Fiber optics: In this case and due to the technology the Research and Development costs will include also Development, Support, and New Equipment costs.

Element of cost	Coefficient	% of cost
Engineering	0.8	0.00034
Fabrication	1.0	0.01117
Development	-	0.08462
Equipment	-	0.08462
Support	-	0.08462
Total R. and D.	-	0.26537

2. Procurement costs

Conventional wiring: The elements of cost included in this category are Manufacturing, Auxiliary Equipment, Engineering and Quality Control.

Elements of cost	% of cost
Manufacturing	0.23363
Auxiliary	0.23533
Engineering	0.02576
Qual. Cont.	0.00347
Tot. Procur.	0.46163

Fiber optics: The same elements of cost apply.

Element of cost	Coefficient	% of cost
Manufacturing	0.80	0.18691
Auxiliary	0.83	0.19532
Engineering	0.80	0.02061
Qual. Cont.	1.00	0.00347
Tot. Proc.	-	0.40631

3. Operating and Maintenance

Conventional wiring: The elements of cost can be divided into two general ones, Non-recurring Investments, and Operating and Support. Non-recurring investments include, Technical Support, Initial Spare Parts, Training of personnel, Specific Support, Test Equipment etc. Operating and Support include, Maintenance Personnel, Equipment for maintenance and Calibration, and Repair material not including Initial Spare Parts and Inventory Management.

Elements of Cost	% of Cost
Non-rec. Nvest.	0.33264
Operat. and Sup.	0.19413
Tot. Oper. and Maint.	0.52677

Fiber optics: The same elements of ccst apply.

Element of cost	Coefficient	% of cost
Non-rec. Invest.	0.94	0.31248
Operat. and Sup.	0.52	0.10130
Tot. Oper. and Maint.	-	0.41378

4. Salvage Costs

Either salvage costs in conventional wiring and Salvage costs in fiber optics can be neglected because of its small influence, if some, on the total life cycle costs, though, the value in the case of conventional wiring will be higher than that of the fiber optics.

E. FINAL COMPARISON OF COSTS

Conventional wiring:

Elements of Cost	% of Cost
Research and development	0.01160
Procurement	0.46163
Operating and Maintenance	0.52677
Total	1.00000

Fiber optics:

Elements of costs	% of cost
Research and development	0.26537
Procurement	0.40631
Operating and Maintenance	0.41378
Total	1.08546

As it can be seen, actually the cost of the system is higher on the newly developed technology, but the difference is not large. The largest difference appears between the Research and Development costs. This is due to the initial phase in which fiber optic technology is at the present time. These costs are likely to decrease in the future. The estimated savings in O and M costs is approximately 20%.

Data about costs in long distance optical links are not available. In this case the optical system has an implied characteristic that increases its cost. The losses in intensity of the signal makes mandatory the use of amplifiers to increase the strength of the signal. These repeaters need to be fed and the power needed has to be carried through conventional wiring, increasing the cost of the system.

There is a trade-off between the amount of information sent and the cost of the system. If the amount of information is great, the implementation of the optical system will be worthwhile. If it is small , the cost will

be prohibitive.

F. EFFECTIVENESS ANALYSIS

To complete the study of the different alternatives, the non-measurable characteristics have to be considered, and some kind of value has to be assigned to each one.

In order to specify the relative importance of each alternative, the different characteristics are to be weighted. These weights will be called 'Coefficients of Effectiveness'.

1. High Bandwidth

The value of this coefficient has to be large enough to represent the difference in bandwidth between both technologies.

2. Immunity from EMI

Depending on the application, the coefficient for electromagnetic interference (EMI) has to be applied a different value. Both extremes can be considered. In the case of an aircraft based on a carrier that has to be exposed to high level of interferences, the value has to be important. In a ground installation, as a buried telephone network, this characteristic is likely not to be considered and its weight not to be applied.

3. Immunity from EMP

The electromagnetic pulse due to nuclear blasts (EMP) is associated with a very small possibility of occurrence of this pulse. Its weight will therefore be small and only applied in the special cases in which the blast would occur.

4. Small Size

In applications in which space is important, as with small devices or overloaded city trunks, this weight has to be considered.

5. Light Weight

Light weight, with the immunity to EMI, is the basic characteristic of fiber optics. It is stated in ref. 11 that the weight of fiber optics equipment accounts for 54% of that of conventional wiring on the application of fiber optics. In the specific ALOFT demonstration in which large changes on the configuration were not allowed and the substitution was made using external equipment tc the original electronics. In cases of original design the savings in weight will be larger.

The weight difference is always important but in the case of satellites, missiles or aircraft in which weight is a premium it is of great importance. This importance will decrease in genaeral applications, though it would be always a saving with respect to overhead and labor costs.

6. Dielectric Isolation

Its advantage is that it eliminates the need of extra protection such as shieldings, etc. Transmitter and Receiver are isolated from each other, which will reduce problems in ground loops. No equalization is required and since the signal path is not a conductor and the fibers are built in such a way as to avoid light beams leaving the fiber, no electromagnetic radiation results, making it also difficult to physically tap This will be of great value in those cases in which security is the prime factor.

7. Safety in Hazardous Environments

Fiber optics cables are considered tough and capable of resisting the hardest environmental conditions. However, if the fiber is exposed to air, its decomposition accelerates and its life time decreases. Because of this, the fibers are coated with a protective substance. If the application implies some kind of movement, that will imply a possible wearing, this will be a disadvantage because the fiber has to be protected and its cost will be higher.

G. COEFFICIENT OF EFFECTIVENESS

To each one of the attributes mentioned above a coefficient has to be applied depending on the specific application of the fiber optic system.

This coefficient is to be applied to the percentage of the total cost found in the paragraph about the fiber optics system with comparison to its value of 1 of the conventional

wiring. Its value has to be less than 1 in such cases in which the fiber optics are considered advantageous, 1 when the characteristic questioned does not imply any advantage and more than 1 when the fiber optics are disadvantageous. The following table lists these coefficients.

VALUES OF THE COEFFICIENT OF EFFECTIVENESS

-----	A	B	C	D	E	F	G	H
EMI	.7/.8	.8	.7/.8	.7/1	.9/1	.8/1	1	.95/1
EMP	1	.95	.8/1	1	.95/1	1	1	.95/1
Size	.7/.8	.7/.8	.7/.9	.7/1	.95/1	.95/1	.99/1	.98/1
Weight	.7/.8	.7/.8	.8/.9	.8/1	.95/1	1	.98/1	.98/1
Hazard	1	1	1	1	1	.95	1.05	1
DielIso	.9	.95	.9	1	1	1	1	.98

Notes:

A=Missiles
B=Satellites
C=Aircraft
D=Droner
E=Shipboard Equipment
F=Control Equipment
G=Communications Networks
H=Secure Communications

The values assigned to the coefficients are an approximation made by the author after the reading of the information available about the topic and his previous experience in studies involving similar decisions. These coefficients were assigned a range from 0.7 to 1.05 which may change in some cases, when extreme constraints appear.

H. TRENDS OF COSTS OF MATERIALS INVOLVED

To have a better estimate about the possible development of this new technique, the trend on prices of the materials used in both cases have to be known. In Ref. 11 the costs are studied in a per unit basis.

1. Conventional Wiring

The percentage of the unit cost of the different materials involved in the fabrication of conventional wire are the following (Ref. 10):

Copper........8.1%
Silver.......72.5%
Plastics.....19.2%
Steel.........0.2%

The forecast in the increase of the price of copper up to the year 2000 is of 77%. That means that the average annual increase will be of 2.5% (Ref. 11).

Silver accounts for the largest percentage in costs. Silver is used in both , the inner and the outer conductors and in the connectors. Its projected average annual increase

up to the year 2000 is about 0.5% The possible variations in external supplies have also been accounted, because today this industry depends 50% on foreign supplies.

The annual average price increase of Iron up to the year 2000 is like that of silver, about 0.5%. Because the percentage of cost of the required iron is 0.2%, an increase on its cost will affect the total price very little.

Because the raw material of plastics is petroleum, its cost can be largely influenced by the variation in the cost of that energy resource whose demand is increasing continuously. The price of plastics experienced a downward trend in the first part of the seventies, maintaining an upward trend after that.

2. Fiber Optic Technology

Being in its development phase, information about the costs of this product is difficult to acquire. Fabricators do not show their specific prices. A certain approach can be used, by looking at its composition. Silica and plastics are the two major components of the cost. The ratio of costs of plastics to silica seems to be about 5 to 1.

The same comments as those above for increasing costs in the conventional wire technology for plastics will apply.

The price of silica can be considered minimal and will not be subject to any change. Quartz, sand, Flint, etc., are the raw materials for the SiO_2, and are abundant in nature.

I. SUMMARY

At this stage in its development, fiber optic technology appears to be advantageous compared to conventional technology for small distance, high speed information transfer links, as those between distributed microcomputer systems. At such distance it is not necessary to use repeaters. Sources are cheaper because of their lower output power. The cost will increase with distance because either higher output power will be needed or the use of amplifiers will be mandatory.

When some of the advantageous characteristics of fiber optics can be used to solve problems that conventional wiring does not, fiber optics will be more effective. The case of a long secure data link may be an example. The use of fiber optics, though more expensive, will avoid operating costs due to the necessity of guards.

Up to now, long distance telephone networks are prohibitive in cost. Many countries are investigating such possibility but the results are only satisfactory when related to technical or secondary problems.

Fiber optic technology is in its Research and Development phase. It would be correct to say that after the initial high costs of this phase and the materials involved in its fabrication become much less expensive, fiber optics technology will be extensively used in the future, above all, if the advantages that its use will carry are economically and rationally exploited.

Although not at the speed that the integrated circuits

decreased their prices, the cost of fabricating optical components will also decrease. all these studies are only forecasts, it is possible that in the near future, this study will have to be changed. At some future time, fiber optics may be an economical alternative to a wide range of problems today not cost effective.

VI. FUTURE TRENDS

A. GENERAL

It is expected that the utilization of fiber optics technology in the future will increase greatly. Today, there exist some problems that inhibit its spread. High costs of the system components, lack of standard parts specifically taylored to the requirements of these systems and unresolved technical problems are the hurdles.

1. High Cost of the Systems

Today's prices can be considered totally unrealistic. This does not mean that fiber optics costs are overvalued but that the Research and Development costs are very high and risky. Because of this manufacturers use large margins. The numbers given about the future dollar value of the market of fiber optics, are only bets without too much solid base. Recent marketing studies predict a $100 million business in fiber optics in the early 1980's. Possibly this number suspiciously rounded to a power of ten, will be reached much sooner. Manufacturers of specific components are preparing for the boom. In every specialized magazine appear continuous improvements. Quantities of money are flowing towards this new branch of industry, which means that in the near future prices will drop rapidly, eliminating the problem of today's high costs.

2. Lack of Standard Parts

Fiber optic communications was helped in the beginning by devices which existed before the development of this technology. Today, LEDs, Lasers, Photo diodes etc., are designed to have as much compatibility between them as possible. Dopping of semiconductors allows the change on the characteristics of the light to which they are related. Sources and detectors are constructed to match with the specific characteristics of the fibers.

If the secondary device market is studied, the future development in this field can be foreseen. The specialized companies are spending money on research in other fields to help in the selling of their own products.

Amphenol is spending money in designing fiber optic systems to sell its connectors. Many other companies, such as Texas Instruments, Radiation Devices, AMP Inc., Centronics, etc. are creating low cost fiber optic kits to help the application designers.

3. Unresolved Technical Problems

The third limiting factor in the development of the fiber optic technology and its application are the technical limitations. In long distance applications the need of power supplies to feed the repeaters is a great limitation. The use of long life batteries, an uneconomic way of feeding devices, and the low power consumption amplifiers will help solve the problem in certain applications , but not entirely.

B. ACTUAL TRENDS

Though fiber optic communications is a unique technology, it is possible to foresee two different trends. One in the field of large communication systems, such as telephone networks and computer networks. The explosion in the amount of information in recent time is gigantic, and to send it over high speed links will become a requirement. The second one is in the field of specific applications, distributed microcomputer networks, ship communications, automobile industry, etc.

1. Actual Changes

Industrial and military systems have used fiber bundles. The telephone industry committed itself to single fibers per channel systems. Today's system designers in the field are shifting away from the bundle concept to the single fiber approach for three reasons: cable design, connector performance, and over all, economics.

2. Huge Networks

As was said before, the need for high speed networks capable of managing huge amounts of information is here. The first users of voluminous information sent through communication links were newspapers. This was done using radio networks to send news to the ships at sea, but the speed of transfer of such information was very low. Today newspapers have editions in different cities with the same information because they send it over a communications network and print it automatically. In the future, not only newspapers but reports, magazines or books will be sent by

this media. Educational service media, videophone, etc. will also be widely used.

The U.S. Post Office is studying the possibility of a system of mailing using communications other than physical media. Computer data bases with information in many fields, will be strategically placed and will be accessed from hundreds of remote locations.

3. Particular Applications

The creation of a communications network in the aircraft carrier *Kitty Hawk* or the substitution of the conventional wiring for fiber optics in the A7 were only the start in the field of specific applications. In the future, the knowledge acquired in the field of integrated circuits will be applied to this closely related field of fiber optics. Substances used in the fiber optic field and those used in integrated electronics are basically the same. This will help solve problems in the fiber optics field.

C. FUTURE APPLICATIONS

Many of the initial applications in the military field are in systems of relatively small size, such as integrated weapon systems that use distributed computer networks involving enormous amounts of devices and relatively low length of fibers, resulting in a high ratio of losses per unit of distance (if the reader allows me to introduce this pseudo measure), or high density of losses.

Relatively soon these small weapons systems will be fabricated in the same way that glass figures are made by the blowed glass artisans. A pre-form of the desired fiber

can be fed into an electric furnace and a fiber can be drawn down without any contact die. The melted body of the preform may be pulled out to form the different branches, and put into shape according to its application, eliminating all the problems related to losses in matching of fibers and couplings.

Sources and detectors will be buried directly on the fiber also avoiding the losses related to the matching. Optical transmitters and receivers will be a reality.

On ships, large aircraft and future spacecraft, where the unique power supply concept is a problem related to reliability in an hostile environment, it will be useful to think of a distributed network of power supplies controlled by computers using fiber optics. This will easily isolate failures in the weaponry due to combat damage. The failure of one of such parts will not cause failures of the others. With this, a ship will be quasi invulnerable, the solution of the water tight compartments will be applied to the power distribution system which in the future will be 'electrotight'

When the problem of the repeaters is studied in parallel with the problem of the solar energy, a solution is evident. Only in such cases where light is not available as in submarine cables, the problem will remain (soon we will see that can be easily solved). The transmission medium will include a section of guide having suitable doped glass with some perturbations which will form a laser cavity. This laser will be excited with sunlight, amplifying the signal. The periods of darkness will be carried out with solar rechargeable batteries in the same fashion that the satellites solve their problem of the earth eclipse.

Since fibers with very low losses will be built, (losses

of 0.47 dB/km are a today's reality) and since amplifiers that need very low power will be used, the phenomenon of the chemical battery at sea can be used. Repeaters with two different electrodes in contact with sea water will supply enough current to drive the amplifiers, allowing their use in submarine cables.

In less than ten years, fiber optic communications will be extensively applied to applications involving electronics.

Power lines will be built and house appliances will be fed with light instead of electronics. The danger of fire will be reduced and a new era will begin.

APPENDIX A

ACTUAL MARKET

A. RESUME OF FIBERS

The characteristics of the fiber as well as some related parameters are given as examples. More information about this can be acquired by consulting the different manufacturers given in Appendix C. (Fig.14).

n1=core refractive index

n2=cladding refractive index

δ=relative refractive index:

$\delta=(n1-n2)/n1$

a=diameter of the core

b=diameter of the cladding

c=cladding thickness:

$c=(b-a)/2$

z1=limit angle of refraction

z2=maximum launch angle

NA=numerical aperture

Numerical aperture as a function of the refractive indexes:

NA=n1*sin z1

NA=n1*sin(arc cos n2/n1)

z1=arc cos n2/n1

l=wavelength of the light

N=number of modes

$N=(0.5*a*PI*NA/2)^2$

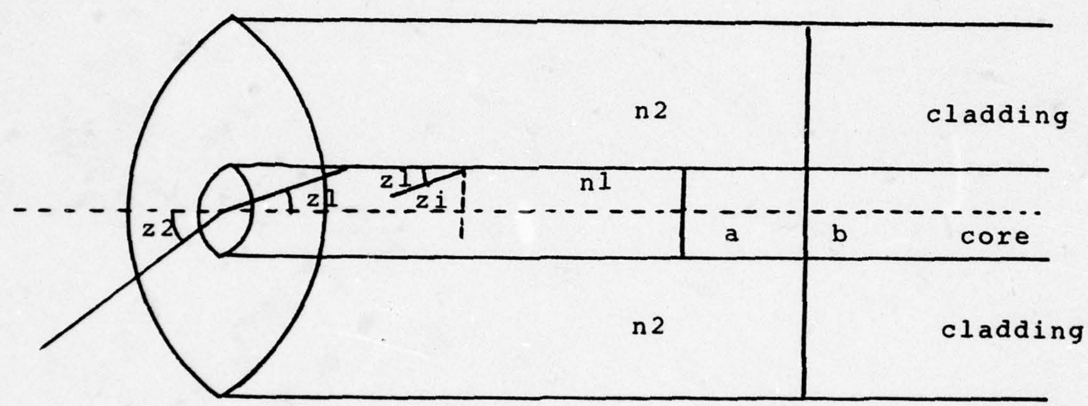


Figure 13 - SUMMARY OF CHARACTERISTICS

Δt=mode dispersion per kilometer

z=solid launching angle:

z=21(1-cos z1)

υ=launching efficiency:

υ=z/total solid angle of the source

Rm=minimum bending radius (cm.)

Lf (wavelength)=attenuation at different wavelengths.

B. ITT

1. Plastic Clad Silica Fiber

Charac/Types	PS-03-35	PS-05-20	PS-05-10
Lf	35	20	10
NA	.3	.3	.3
Δt (10/3dB width, ns.)	60/30	60/30	60/30
n1	1.46	1.46	1.46
a(micrometers)	125	125	125
b(micrometers)	300	300	300
Rm(cm.)	.5	.5	.5

2. Step Index Multimode Optical Fiber

Charac/Types	GS-02-12	GS-02--8	GS-02--5
Lf(.85/1.06micromet.)	12/8	8/5	5/3
NA	.25	.25	.25
Δt (10/3dB width, ns)	30/15	30/15	30/15
n1	1.48	1.48	1.48
a (micrometers)	50	50	50
b (micrometers)	125	125	125
Rm (centimeters)	0.5	0.5	0.5

3. Gradex Index Multimode Optical Fiber

Charact/types	GG-02-12	GG-02--8	GG-02--5
Lf(.85/1.06 mmeters)	12/8	8/5	5/3
NA	.25	.25	.25
Δt(10/3dB width, ns.)	5.0/2.5	5.0/2.5	5.0/2.5
n1 (on axis)	1.48	1.48	1.48
a (micrometers)	50	50	50
b (micrometers)	125	125	125
Rm (centimeters)	0.5	0.5	0.5

4. Fiber Optics Cable

Type Character.	Single Fiber strengthened	Internal Heavy duty	Light duty Type LD	External Heavy duty
num. of Fib.	1	6	7/19	7
a(PS, GS-GG)	125,50	125,50	125,50	125,50
Wght.(kg/km)	6	30	6.4	30
Rm (cm)	2.5	5	2.5	5

C. CORNING GLASS

1. Corguide cable

Types	1300	1302
Types	1300	1302
Characteristics		
Profile	Step	Gradex
Lf (.82 micrometers)	20	20
NA (90% opt. power)	0.18±0.02	0.16±0.02
a(micrometers)	0.085	0.062
b (micrometers)	0.125	0.132
Δt (3dB, ns.)	23	2
Num. of Fib.	7	7
Whgt (kg/km)	25	25

APPENDIX B

OPTICAL FIBER DIGITAL TERMINALS

A. GENERAL

Electronic and optical interfaces have to be implemented. Originally the designers of particular applications, designed its specific interface, according to the characteristics of the system they intended to build. In recent times, due to fast growth in the number of applications, manufacturers began to build and sell standarized interfaces. As integrated circuits are extensively used in electronic applications, voltages and power levels compatible to integrated circuits have to be used. The more important characteristics to look for are the compatibility of the interfaces to the digital logic.

There are many manufacturers in this field, but only a few tabulated, to serve as a guide for the system designer.

B. ITT

The optical fiber Digital Terminal, Model 2-D is a digital fiber optic transmission system capable of data rates between 20 Kbits/sec. and 20 Mbits/sec. Inputs and outputs are TTL compatible, with amplitude regenerated data

output. The transmitter uses an LED with four selectable drive current settings to give flexibility to the optical output power. The receiver features an avalanche photo diode detector. Model 2-D includes the appropriate power supplies.

The Model 2-d characteristics are the following:

Upper bit rate cut off	20 Mbit/se.
Low cutoff (10% analg. drop)	500 Hz. square wave
TRANSMITTER:	
Input impedance	50 ohms or 4 TTL
Max input signal level	5 V.
Power supply	5±0.25 VDC
Opt. outp. power (GS-02 grad.)	30 microwatt
Opt. outp. power (GS-02 step.)	60 microwatt
RECEIVER:	
Output imped. (digit.)	50 ohms.
Output imped. (analog)	600 ohms
Analog out signal level	3 v. p-p, nom
Power supplies	5v±0.25VDC at 75 ma.
-----	8 to 18VDC at 100 ma.
-----	-8 to -18VDC at 75ma.
Optical sensit. at $1/10^8$, BER	6 nw. peak
Optical dynamic range	20 dB.
Rise/fall time (digit.)	8 ns. max
Rise/fall time (analog)	20 ns. max

C. SPECTRONICS

Three different 'optical transmission line systems'. the SPX 2674 for high speed digital communications, the SPX 2672 for medium speed digital systems and the SPX 2673 for analog video signals.

1. SPX 2674

It is designed to be used in high speed data transmissions up to 10 Mbit/sec. Input and Output are TTL compatible.

Specifications:

Speed	10 Mbit/s. (Manchester)
BER	$1/10^8$ at max. speed.
Input level	TTL
Output level	TTL
Power reqs. (Tx.)	5 VDC at 200 ma.
Power reqs. (Rx.)	115v 50-400 Hz. .95ma

2. SPX 2672

Designed for low-medium speed data transmissions, from DC to 100 Kbits/sec. Input and output are TTL compatible.

Specifications:

Speed	100 Kbit/s. NRZ
-----	50 Kbit/s. (Manchester)
Error rate	1/10⁸ at max. speed
Input signal req.	Single ended, TTL
-----	Di. 500mV. at ±3v.
Output signals	Single ended CTTL
-----	dif. 1.95 V.,min
Power reqs, (Tx.)	5 VDC at 100 ma. max.
Power reqs, (Rx.)	5 VDC at 50 ma. max.

3. <u>SPX 2673</u>

Designed to transmit wideband analog information from point to point. An 1 volt peak to peak signal has to be applied to the input. The output reproduces such signal at the same level.

Specifications:

Frequency response	1dB from 10 Hz to 50Mhz
Input signal	1 volt peak
Input impedance	75 Ohms
Overshot	5% max.
Noise	60 dB volt.
Output signal	1 v. peak to peak
Output impedance	75 ohms.
Power reqs. (Tx.)	115v. 50-400 Hz. 0.5A
Power reqs. (Rx.)	115v. 50-400 Hz. 0.5A

APPENDIX C

LIST OF MANUFACTURERS

A. MANUFACTURERS

A list of Manufacturers of fiber optics communications components is given .

B. FIBER OPTICS

American Optical Corporation:
14G Mechanic, Southbridge, MA 01550 (617)875-9711

Corning Telecommunications Prods. Div.:
Corning, New York 14830, (637) 974-8812

Ealing Optics Corporation:
2225 Massachusetts Ave. Cambridge, MA 02140 (617) 491-5870

Edmund Scientific Co:
101 E. Gloucester Pike, Barrington NJ 08007 (639)547-3488

E.I. Dupont De Nemours Co.:
Wilmington , Delaware 19898 (302)774-7850

Fiber Optic Cable Corp.:
P.O Box 1492, Framingham, MA 01701, (617)875-5530

Phiberphotics:

2257 Soquel Dr. Santa Cruz CA 95060 (408)475-5242

Galileo E/O Corp

Galileo Park, Sturbridge MA 01518 (617)347-9191

General Cable Corp.:

500 Putman Ave., Greenwich CT 06830 (203)661-0100

ITT Electro Optical Prods.:

7635 Plantation Rd.,Roanoke VA 24019 (703)563-0371

Poly Optics Inc.:

1815 E Carnegie, Santa Ana, CA 92705 (714)546-2250

411 E Jarvis Ave. Des Plaines IL 60018 (312)297-7720

Valtec Corp.:

99 Hartwell St. West Boylston MA 01583 (617)835-6382

C. LEDS AND LASERS

Aborn Elctronics:

1928C Old Middlefield Rd., Mountain View, CA 94043 (413)327-7424

Bell Northern Research Ltd.:

P.O. Box 3511,Station C, Ottawa, Canada K17 4H7 (613)596-2210

Centronic:

1101 Bristol Rd., Mountainside, NJ 07092 (201)233-7200

Fairchild Microwaves Optoelectronics Division:

4001 Miranda Ave., Palo Alto, CA 94303 (415)493-3200

General Electric Corporate R D:
1 River Rd. Schenectady, NY 12345 (518)257-8771

International Audio Visual Inc.:
15818 Arminta St. Van Nuys, CA 91406 (213)784-4400

ITT Electro optical Products Div.:
7635 Plantation Rd.,Roanoke VA 24019 (201)549-7700

Laser Diode Labs. Inc.:
205 Forrest St., Metuchen, NJ 08840 (201)549-5700

Litronix, Nc:
1900 Homestead Rd., Cupertino CA 95014 (408)257-2140

Meret, Inc.:
1050 Kenter Ave., Los Angeles CA 90049 (213)828-7496

Monsanto Electronic Special Products.:
3400 Hill View Ave., Palo Alto.CA 94304 (408)257-2140

Motorola Semiconductors.:
Box 20912 Phoenix AZ 85036 (602)962-3186

RCA Electro Optics Div.:
New Holland Ave., Lancaster PA 17604 (717)397-7661

Spectronics Inc.:
541 Sterling Dr., Richardson TX 75080 (214)234-4271

Texas Instruments.:
Mail Station 12 PO Box 5012, Dallas TX 75222 (214)238-4561

D. PHOTO DIODES

Aborn Electronics.:
1928C Ld Middlefield Rd., Mountain View, CA 94043 (415) 327-7424

Centronic:
1101 Bristol Rd. Mountain Side NJ 07092 (201) 233-7200

Dewar, Nc.:
706 Bostwick Ave., Bridgeport CT 06605 (203) 368-6751

EG G, Inc.:
35 Congress st., Salem MA 01970 (617) 745-3200

Fairchild Microwave Optoelectronics Div.:
4001 Miranda Ave., Palo Alto CA 94303 (415) 493-3100

Hewlett Packard:
620 Page Mill Road, Palo Alto CA 94303 (415) 493-1212

Inotech:
181 Main St., Norwalk, CT 06851 (203) 846-2041

Laser Diode Labs. Inc.:
205 Forrest St., Metuchen NJ 08840 (201) 549-7700

Monsanto Electronics Special Products:
3400 Hillview Ave. Palo Alto, CA 94304 (415) 493-3300

Motorola Semiconductors:
Box 20912 Phoenix AZ 85036 (602) 244-4556

Quadrant Corp.:
2261G South Carmelina Ave., Los Angeles CA 90064 (213) 478-0557

RCA Electro Optics Div.:
New Holland Ave, Lancaster, PA 17604 (717) 397-7661

Spectronics Inc.:
830 E Arapaho Rd. Richardson TX 75083 (214) 234-4271

Texas Instruments.:
PO Box 5012 Dallas TX 75222 (214) 238-3274

UDT, Inc.:
2644 30th St., Santa Monica CA 90905 (213) 396-3175

E. CONNECTORS

AMP Inc.:
Box 3608, Harrisburg PA 27105 (564) 235-0100

Amphenol Bunker Ramo Corp.:
33 E Franklin Ave., Danbury, CT 06810 (203) 743-9272

Burndy Corp.:
Richards Ave. Norwalk, CT 06856 (203) 834-4444

Cannon Electric:
666 Dyer Rd., Santa Ana CA 92702 (714) 557-4700

Radiation Devices:
PO Box 8450 Baltimore MD 21234 (301) 628-2240

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The Deutsch Co.:
Municipal Airport Banning CA 92220 (714) 849-6701

F. FIBER OPTICS SYSTEMS

Bell Northern Research Ltd.:
PO Box 3511, Station C Ottawa, Canada K17 4H7 (613) 596-2210

Centronic:
1101 Bristol Rd., Mountainside NJ 07092 (201) 233-7200

Corning Telecommunications Prod Div.:
Corning NY 14830 (607) 974-8812

ITT Cannon Electric:
666 Dyer Rd. Santa Ana CA 92702 (714) 557-4700

ITT Elctro Optics Prods.:
7635 Plantation Rd. Roanoke VA 24019 (703) 563-0371

Meret Inc.:
1815 24th St. Santa Monica CA 94404 (213) 828-7496

Quadri Corp.:
1725 W 17th St. Tempe Az 85282 (802) 894-2151

Radiation Devices:
Po Box 8450, Baltimore MD 21234 (301) 628-2240

Spectronics Inc.:
830) Arapaho Rd., Richardson TX 75080 (214) 234-4271

Times Fiber Communications:
550 Research Parkway, Meriden CT 06450 (203)634-2171

Valtec Corp.:
99 Hartwell St., West Boylston, MA 01583 (617)835-6082

G. FIBER OPTICS KITS

AMP Inc.: Box 3608, Harrisburg, PA 17105 (717)546-0100

Centronic:
1101 Bristol Rd. Mountainside NJ 07092 (201)233-7200

Texas Instruments:
PO Box 5012 Dallas TX 75222 (314)238-2011

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